

β - AND γ -COMPARATIVE DOSE ESTIMATES ON ENEWETAK ATOLL*

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Abstract—Enewetak Atoll is one of the Pacific atolls used for atmospheric testing of U.S. nuclear weapons. Beta dose and γ -ray exposure measurements were made on two islands of the Enewetak Atoll during July–August 1976 to determine the β and low energy γ -contribution to the total external radiation doses to the returning Marshallese. Measurements were made at numerous locations with thermoluminescent dosimeters (TLD), pressurized ionization chambers, portable NaI detectors, and thin-window pancake GM probes. Results of the TLD measurements with and without a β -attenuator indicate that approx. 29% of the total dose rate at 1 m in air is due to β - or low energy γ -contribution. The contribution at any particular site, however, is somewhat dependent on ground cover, since a minimal amount of vegetation will reduce it significantly from that over bare soil, but thick stands of vegetation have little effect on any further reductions.

Integral 30-yr external shallow dose estimates for future inhabitants were made and compared with external dose estimates of a previous large scale radiological survey (En73). Integral 30-yr shallow external dose estimates are 25–50% higher than whole body estimates. Due to the low penetrating ability of the β 's or low energy γ 's, however, several remedial actions can be taken to reduce the shallow dose contribution to the total external dose.

INTRODUCTION

Enewetak Atoll is one of the Pacific atolls used for testing of U.S. nuclear weapons. A large-scale radiological survey was conducted in 1972–1973 (En73) to determine dose estimates for future inhabitants (Gu75a). Those whole body dose estimates are due primarily to energetic γ 's, mainly from ^{137}Cs and ^{60}Co . A subsequent radiological survey of Bikini Atoll (another former U.S. nuclear weapons testing site) indicated, however, that perhaps as much as 25% of the total external exposure rate is due to β or low energy γ -radiation (Gu75b). In August, 1976, β - and γ -dose measurements were made at Enewetak Atoll

to determine the β or low energy γ -contribution to the total external dose, its dependence on ground cover, and the impact on external dose estimates for future inhabitants.

Enewetak Atoll is located in the northeastern part of Micronesia about 3800 km southwest of Honolulu. Forty islands on a coral reef ring a lagoon of approx. 40 km dia. (Fig. 1). The largest islands and consequently most important for future villages and agriculture, are Enjebi (Janet) and Bokambako (Belle) in the northern half of the Atoll, and Enewetak (Fred), Medren (Elmer) and Japtan (David) in the southern half.

Most of the more than 40 nuclear weapons tests at Enewetak were conducted in the northern region of the atoll, with approximately half tested over the lagoon or ocean areas and the remainder tested on several northern islands. Therefore, the

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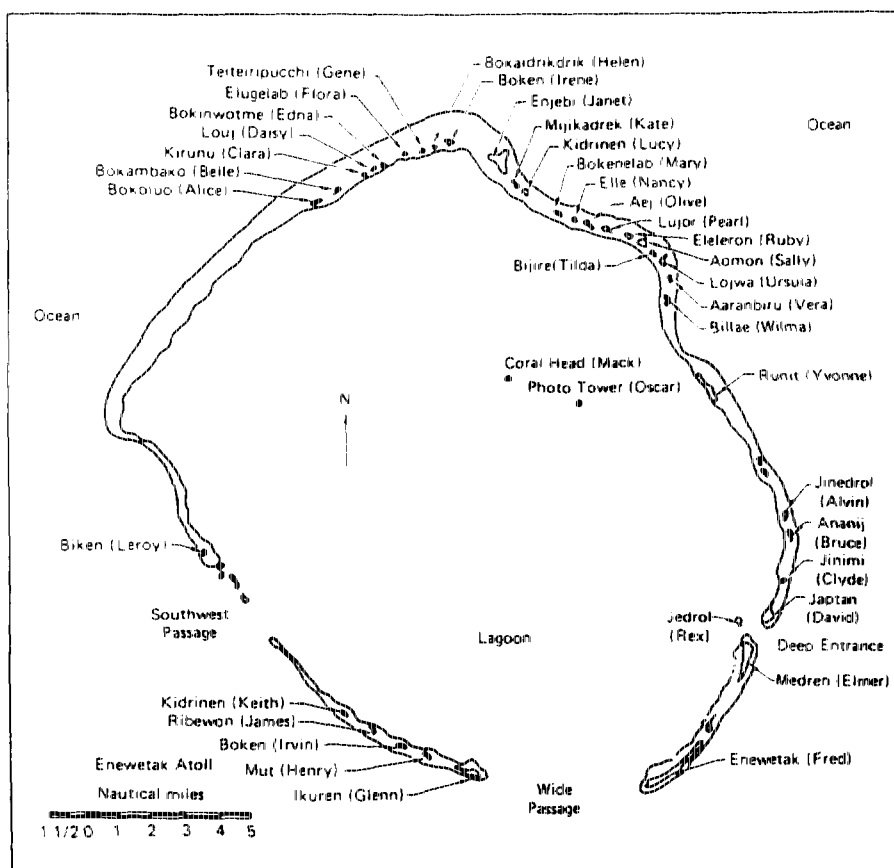


Fig. 1. Map of Enewetak Atoll.

major radioactive contamination and hence radiological impact was to the northern half of the atoll.

Two of the largest northern islands (Enjebi and Bokambako) were used for this study because of their higher soil radionuclide concentrations and the potential use of Enjebi as a residence and agricultural island. Comparative β - and γ -dose measurements were made at a total of 87 locations on these two islands with thermoluminescent dosimeters, pressurized ionization chambers, portable sodium iodide detectors, and pancake GM probes. Locations were carefully selected to represent a wide range of exposure rates and variety of ground cover.

MEASUREMENT METHODS

A portable instrument with a 2.5 cm dia. \times 3.8 cm NaI crystal and ratemeter readout was used primarily for selection of measurement location. External exposure rate measurements were made at a height of 1 m at 67 locations with a pressurized ionization chamber which consists of a stainless steel sphere filled with high pressure argon, connected to an electrometer with digital readout. Calibration of this instrument was verified by DOE laboratories prior to the survey. Although insensitive to β - or low energy γ -radiation, it is sensitive to cosmic radiation, since it has a relatively flat energy response from about 0.1–10 MeV which more

than covers the γ -ray energy range encountered in this survey (Gu75a).

The primary technique used to determine the β - or low energy γ -contribution to the external dose rate was measurements made with LiF TLDs. The response of all dosimeters were matched to within $\pm 2\%$ prior to being used in this survey. Each dosimeter was annealed at Enewetak Atoll immediately prior to placement on the two islands. To protect the TLDs from environmental factors, such as rainfall and dust, during the 3 month exposure period, the Lawrence Livermore National Laboratory (LLNL) personnel dosimeter badges were used. Three dosimeters were placed into each badge, while a blank badge was fastened on top for added protection. At each of 80 locations, two sets of these badges with each containing three TLDs were placed into holes drilled in a wooden crossbar mounted 1 m above the ground on a wooden stake. One of these sets was surrounded with an additional 860 mg/cm^2 aluminum attenuator to allow only the energetic γ -component to be recorded. To determine the effect of ground cover on the β and low energy γ contribution, an array of TLDs, surrounded by various attenuator thicknesses, was also positioned at a height of 1 m at each of seven locations exhibiting a range from minimal to very dense vegetation. An aluminum framework 46 cm wide, 92 cm long and 1 m high was used for these experimental stands. Three pieces of aluminum bar stock, with holes drilled in each to accommodate four sets of TLD badges with various amounts of aluminum shielding, were bolted across the top of each stand. Twelve TLD badge sets were therefore used at each location, shielded top and bottom by various aluminum absorber thicknesses. Control TLD sets were stored inside a lead pig on a southern island with minimal radioactivity. All TLD badge sets were retrieved approx. 3 months later and transported back to LLNL inside a lead pig for evaluation. A calibration of the dosimeters was made with a ^{137}Cs source prior to deployment, while a second calibration was carried out before evaluation to determine fading and transit exposure.

A pancake GM probe with a 7.62 cm dia. thin window, lead γ -shield and digital readout was used for comparative purposes. Measurements with this portable active instrument were made at 34 locations. At each location, two measurements were made at 1 m height; one with no attenuator and one with an 860 mg/cm^2 attenuator over the window.

RESULTS

Figure 2 shows the comparison of γ exposure rates at 1 m in air measured with the LiF TLDs and a pressurized ion chamber. The TLDs were shielded against β 's, and their responses reduced for background (mostly cosmic radiation) as measured by controls. The ion chamber readings were reduced by $3.3 \mu\text{R/hr}$, the cosmic ray exposure rate contribution at that latitude (Gu75b). The dashed line represents a 1:1 relation between the two measurement techniques. The solid line is the result of a linear regression analysis of the data corrected for background, and yields agreement between the two methods within 4%. There is an offset of about $3 \mu\text{R/hr}$ between the data regression and a 1:1 relation, which probably indicates a difference of background subtraction methods between the two measurement techniques.

Similar measurements made with a β -

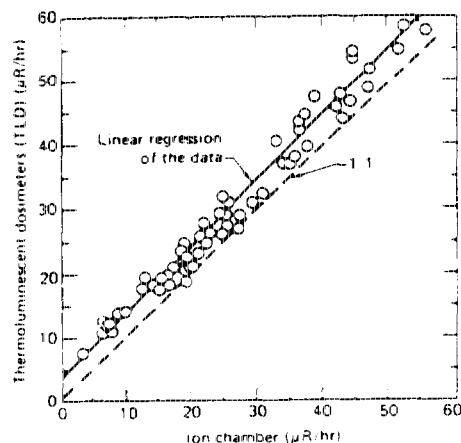


Fig. 2. Comparison of γ -exposure rates measured with TLD and pressurized ion chamber.

shielded GM pancake probe when compared with ion chamber readings resulted in a much wider data spread than did the TLD, due to poor counting statistics in the pancake probe readings (approx. 200 cpm/25 μ R/hr). The linear relationship in the data does, however, indicate that the hand carry pancake GM probe could be used with some sacrifice in precision in areas impractical to reach with the ion chamber.

The β -attenuation measurements made at seven locations are shown in Fig. 3. Two experimental stands were placed in very thickly vegetated areas, such as closely packed clumps of grass 15 cm or more in height or thick patches of large-leaf vines. The top curve in Fig. 3 represents these two stands; extrapolation of the data shows that only about 20% of the dose rate in air at a height of 1 m is due to β -contribution. Two stands were placed in areas of medium vegetation (15 cm or less in height, but mostly covered). These data extrapolate to a β -contribution of about 30%. Three stands, located in areas of minimal or no ground cover, resulted in the lower two curves of Fig. 3; the β -contribution varies from about 50% (lower curve) in a completely bare location, to about 40% in two areas with minimal ground cover. Although the general shape of the attenuation curves is similar for all three ground cover conditions, there is considerable difference in relative response for greater than about 1000 mg/cm² of absorber. The difference in beta

attenuation between thick and medium ground cover is not so distinct as the difference between medium and minimal ground cover, indicating that a relatively small amount of ground cover reduces the beta contribution at 1 m considerably (i.e. from 50% at bare locations down to about 30% at medium locations, then down only to 20% at thickly vegetated locations).

The ratios of TLD responses for attenuated dosimeters were determined at 80 locations in an attempt to correlate these ratios with vegetation density (Fig. 4). The measured contribution of β - or low-energy γ - to the total exposure rate varied between 16 and 59%, with a median of 29%. Although a wide variety and extent of ground cover were represented in these 80 locations, the deviation in the data is less than 13% at 1 σ , suggesting that a median of 29% of the total dose rate at 1 m can be used with sufficient accuracy for estimates of doses to the skin and eyes of future inhabitants. Attempts to categorize TLD locations with respect to vegetation density and β -contribution were unsuc-

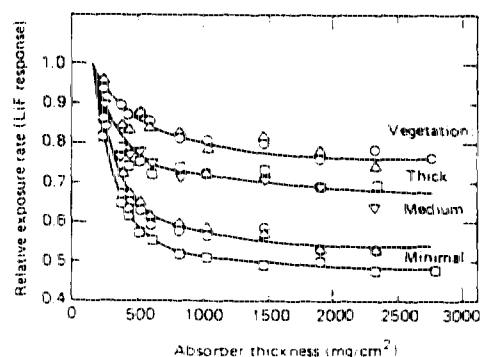


Fig. 3. β -attenuation curves for different ground cover conditions. Two sets of data points were used to construct the top three curves.

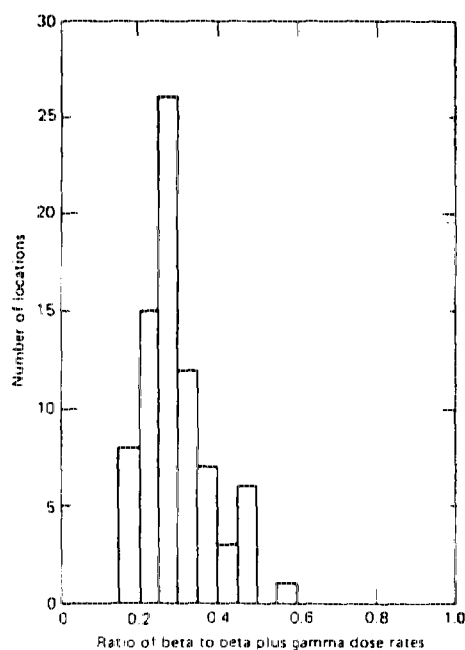


Fig. 4. Distribution of ratios of β : β plus γ -dose rates.

cessful, partly due to differing concentrations of ^{90}Sr and ^{137}Cs in the soil, but largely due to changes in the nature and extent of vegetation over a 3-month period. Locations originally categorized as thickly vegetated did have a slightly lower median β -ratio (25%), but these differences are not large enough to warrant categorizing projected β doses according to vegetation density.

CONCLUSIONS

Previous soil surveys indicated the primary radioisotopes contributing to the external dose rate are ^{137}Cs and ^{60}Co for γ 's and $^{90}\text{Sr}/^{90}\text{Y}$ for β -contribution (En73, p. 103). External dose estimates for future inhabitants were based on aerial γ -surveys and did not include β -contributions and shallow dose estimates. The major finding of the work reported herein is that approx. 29% of the total external dose rate on Enewetak Atoll is

due to β or low-energy γ -radiation. Marked deviations from 29% can be found at specific locations since this contribution is somewhat dependent on ground cover. A little vegetation will reduce the β -contribution significantly from that over bare soil, while dense vegetation have little effect on any further reductions.

The impact of such a significant fraction of the total external dose rate resulting from β - or low-energy γ -radiation is illustrated in Table 1, where integral 30-yr shallow dose estimates are compared with 30-yr whole body doses reported in the 1972 survey. Living patterns and external dose estimates represent assumptions as to village location, other islands visited, and agriculture patterns (En 73). They are listed in Table 1 and can be located on the map in Fig. 1. Living patterns I and II are for residence in the southern islands, and patterns III-VI are for residence

Table 1. 30-Year integral external dose comparisons

Living Pattern	External Whole Body Doses (rem) from reference (En73) with natural background*	Shallow External Doses (rem)
	Subtracted	
I	0.030	0.010
II	0.80	0.44
III	3.2	1.1
IV	9.2	2.4
V	2.1	0.73
VI	3.6	1.5

Assumed Living Patterns for Future Enewetak Atoll Inhabitants

Case	Village Island	Visitation Area	Agricultural Area
I	Enewetak (Medren)	Jinedroi-Kidrinen (Keith)	Jinedroi - Kidrinen (Keith)
II	Enewetak (Medren)	Bokoluo - Billae	Mujukadrek - Billae - Biken
III	Enjebi	None	Enjebi
IV	Bokambako	Bokoluo - Billae	Bokambako
V	Enjebi	Mujukadrek - Billae	Mujukadrek - Billae - Biken
VI	Enjebi	Bokoluo - Biken	Bokoluo - Biken

Fishing from entire Atoll assumed for all cases.

From Table 204, page 613 of reference (En73).

* Natural background: 0.027 rem/yr or 0.80 rem/30 years.

in the northern part of the Atoll. External dose rates are much lower in the southern part of the Atoll. The living patterns include approx. 20% of the time spent visiting other islands, except for pattern III, in which residence, visitation and agriculture are confined to one island.

The estimated β - or low-energy γ -doses are listed in Table 1 as "shallow" doses, in keeping with the concepts set forth in ICRU 25 (Co76). The energy deposited by ^{90}Sr in tissue is predominantly within the first centimeter (Ha75). The integral 30-yr external doses due to β 's or low-energy γ 's vary from 1/4 to 1/2 of the total external integral doses, depending on the living pattern chosen. The variability is due to differences in relative soil concentrations for ^{137}Cs , ^{60}Co and ^{90}Sr as a function of time on different islands. The integral external doses in Table 1 include no assumptions about modifications which could be made to reduce external dose rates; remedial actions, such as providing clean coral gravel around villages or plowing the soil, could very substantially reduce the external shallow dose contribution.

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